Coastal Processes, Historic Shoreline Change, and Sediment Distribution of Portage Bay, Lummi Indian Reservation, WA

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Abstract
Several recent Coastal Geologic Services studies that defined coastal processes in discrete areas with important nearshore habitat resources will be discussed. Nearshore habitats have formed because of the dynamic equilibrium between natural bluff sediment input to the net shore-drift system and the existing wave climate. The presence and maintenance of these habitats is completely dependent on continued bluff sediment input and the lack of disturbance to the net shore-drift (littoral) system, and therefore science-based management plans are essential. A report on Port Townsend Bay and northern Hood Canal was prepared for Jefferson County, in conjunction with a nearshore habitat characterization. Three types of critical shoreline areas for maintaining the critical nearshore habitats were mapped: feeder bluff, contributing bluff, and accretion shoreform. A second CGS study on the eastern Clallam County was completed in 2001. This study provided a long-term shoreline change and coastal processes context in which to consider applications for shoreline modifications. The report included recommendations for shoreline management regarding shore defense proposals. A third study in south Birch Bay was prepared for Whatcom County in 2002. This study included geologic and coastal processes, historic shoreline change, inventory work, and recommendations for non-structural coastal erosion control options.

Introduction
The purpose of this study was to accurately define sedimentary processes in Portage Bay and immediately adjacent areas of the Lummi Indian Reservation, Whatcom County (Figure 1), utilizing both historic information and present conditions. This information will be utilized to define baseline conditions, help understand the presently high fecal coliform levels in Portage Bay, and to provide guidance for management of nearshore marine, coastal, and adjacent upland areas on the Lummi Indian Reservation.

The extent of continuity in sediment transport over time along the large spits bounding Portage Bay known as The Portage and Brant Spit has been in question both academically and practically. Defining the stability of these spits and trends of sediment transport patterns should greatly aid in understanding water circulation in the bay and the extent to which circulation may have changed or will change over time. An increased understanding of water circulation will contribute substantially to the understanding of the distribution of fecal coliform in the waters of Portage Bay and will complement past and future drifter/drogue and salinity-based measurements of water circulation in Portage Bay. Changes in the two large spit complexes that surround Portage Bay substantially alter the water circulation in the bay and consequently change the amount of flushing and the fecal coliform contamination patterns.

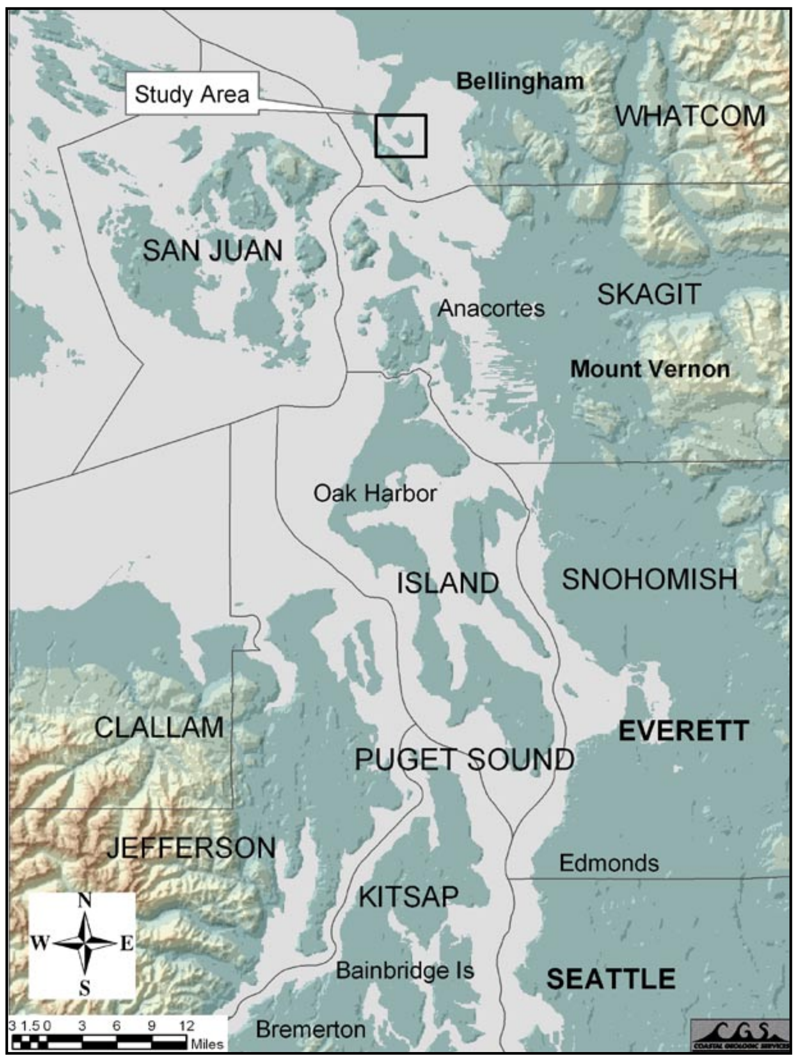

Figure 1. Study area location map showing Puget Sound and Northwest Straits.

The term The Portage refers to the tombolo connecting the western shore of Portage Island to the Lummi Peninsula. The spit connected to the northeastern shore of Portage Island is referred to as Brant Island and spit, and the spit north of Brant Island is referred to as the North Spit; following the nomenclature of Vonheeder (1972).

Shoreline Change

GIS Shoreline Mapping Methods

Historical aerial photographs from various entities, a T-sheet, and US Coast and Geodetic Survey nautical charts were used to develop a digital shoreline change map (Table 1). Contact prints made from the original 9”-by-9” negatives were collected, scanned, and orthorectified as TIFF images. The digital orthorectified images were imported into ArcMap v8.2.

Table 1. Portage Island shoreline change analysis: maps and aerial photos used.

Year	Description	Feature delineated
1887	T-sheet #01797c	Sediment Break & MHW
1967	USC&GS Nautical Chart #6378	MHW line
1989	USC&GS Nautical Chart #6378	MHW line
1947	Nat’l Archive BW aerials	High tide beach/low tide terrace
1978	DNR BW aerials	High tide beach/low tide terrace
1999	Lummi color low tide aerials	High tide beach/low tide terrace

Features commonly used in shoreline mapping such as the mean high water (MHW), dune line, and vegetation line (for examples see Stafford and Langfelder 1971; Dolan and Hayden 1983; Morton 1991) were examined and found not to show up well on the aerial photos. The intersection of the high tide beach and the low tide terrace was found to be the feature that was captured by the aerial photos most often, due to a sharp tonal difference present at the break in slope. The high-tide beach, which is composed primarily of rounded gravel, dries quickly to a very light gray tone. The low-tide terrace, which has a much flatter slope and composed of a variety of sediment sizes and brown algae embedded in relatively fine-grained sediment, remains a dark color at all low tides. Photos that were taken at higher tides were not used because the feature was unidentifiable. All aerial images, both digital and prints, were examined to determine the location of the break in slope between the high tide beach and the low tide terrace. Polygons were then heads up digitized, at a 1:4,000 scale, along this feature in ArcMap 8.2 for the 1947, 1978, and 1999 images using the best available images.

USC&GS nautical charts from 1967 and 1989 were rectified to NAD27 or NAD83 tick marks using the Georeferencing tool in ArcMap 8.2. The shoreline was heads up digitized, at a 1:4,000 scale as polygon features in ArcMap 8.2, representing the MHW line.

A sample of results is shown in Figures 2-4. Results of the shoreline change analysis are summarized in the *Summary and Discussion* section.

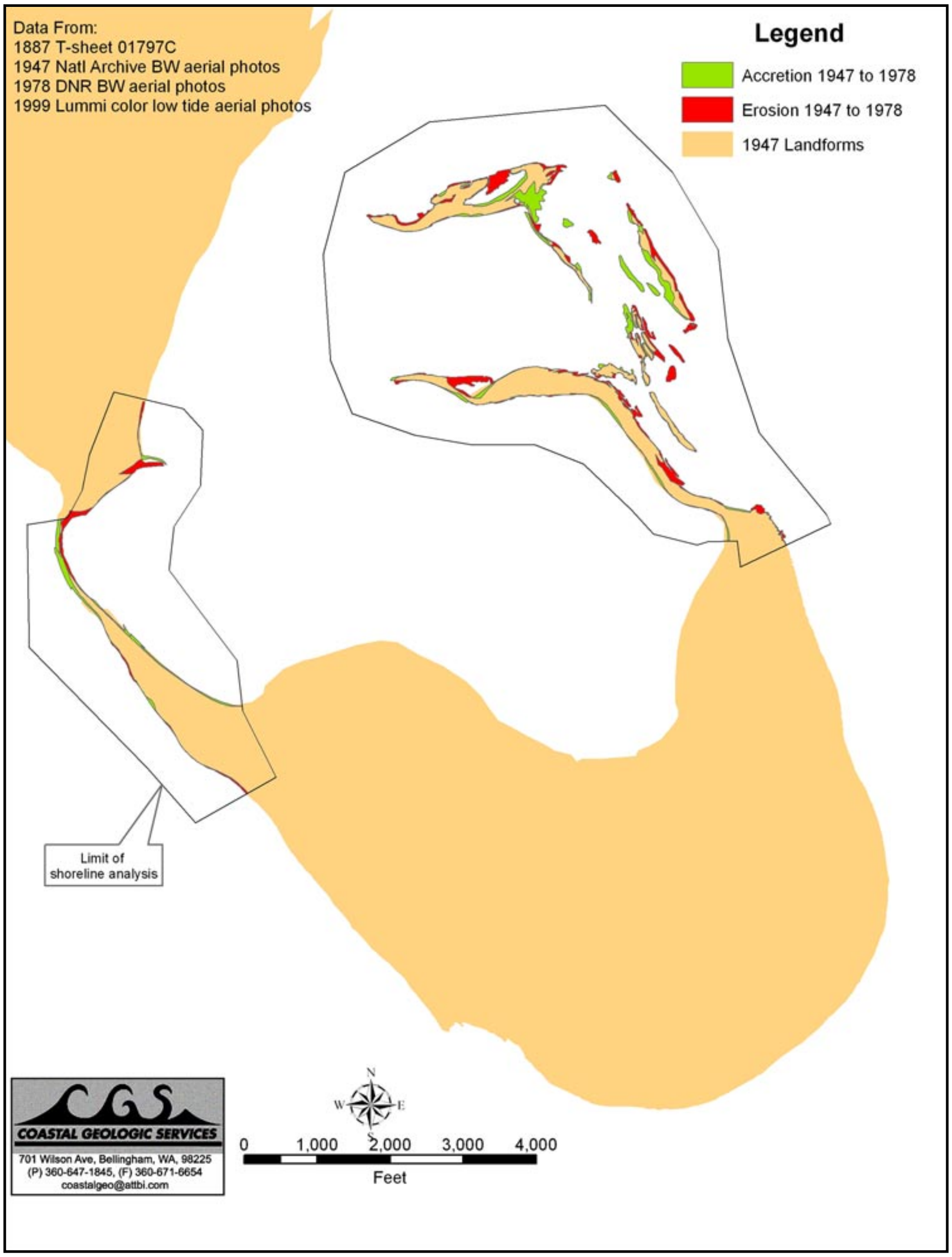

Figure 2. Portage Bay Beach (HT/LT) Change Analysis - 1947 to 1978.

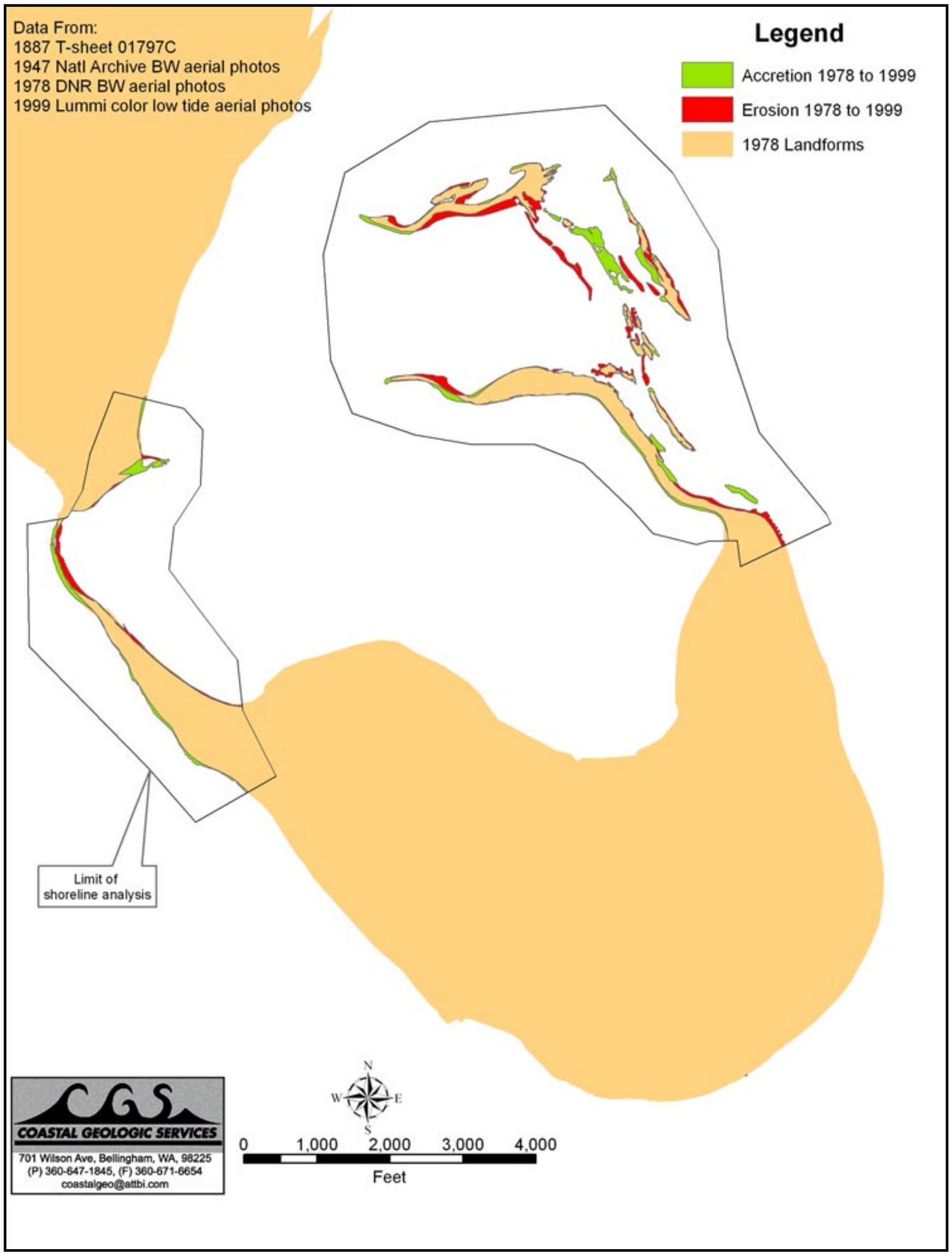

Figure 3. Portage Bay Beach (HT/LT) Change Analysis - 1978 to 1999.

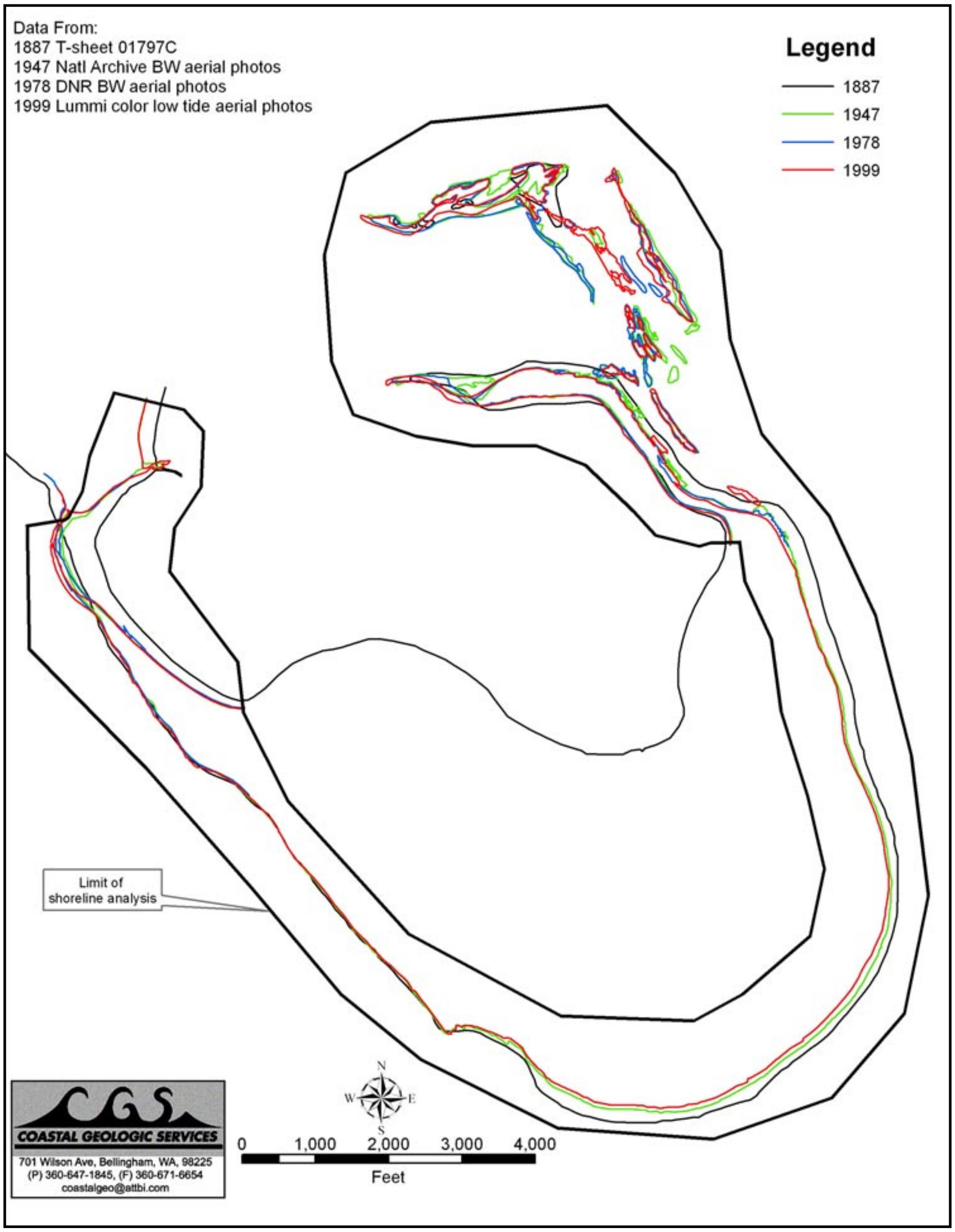

Figure 4. Portage Bay Beach (HT/LT) Change Analysis - 1887 to 1999.

Cross Shore Transects Using GIS Shorelines
Transects were drawn at approximately 1,000-ft intervals along the shore of the Portage, Portage Island, Brant Island and Brant Island Spit. Cross shore accretion and erosion lengths were then calculated in feet using the measure tool in ArcMap 8.2. Bluff toe erosion along the southern and eastern shores of Portage Island were calculated by point measurements cross shore from large boulders to the vegetation line.

The Portage—Transects across The Portage (Figure 5) revealed a narrowing and westward migration of the tombolo (Table 3a). From 1887 to 1947, most of the transects reveal a narrowing of The Portage from erosion on both sides with greater erosion on the bayside shoreline (east side). From 1947 to 1978 there was a further westward migration of the northern end of The Portage at transects A and B, while the southern end moved east at transects C and D. From 1978 to 1999 all transects show migration to the west, with a slight widening of the northern half and slight narrowing of the southern half.

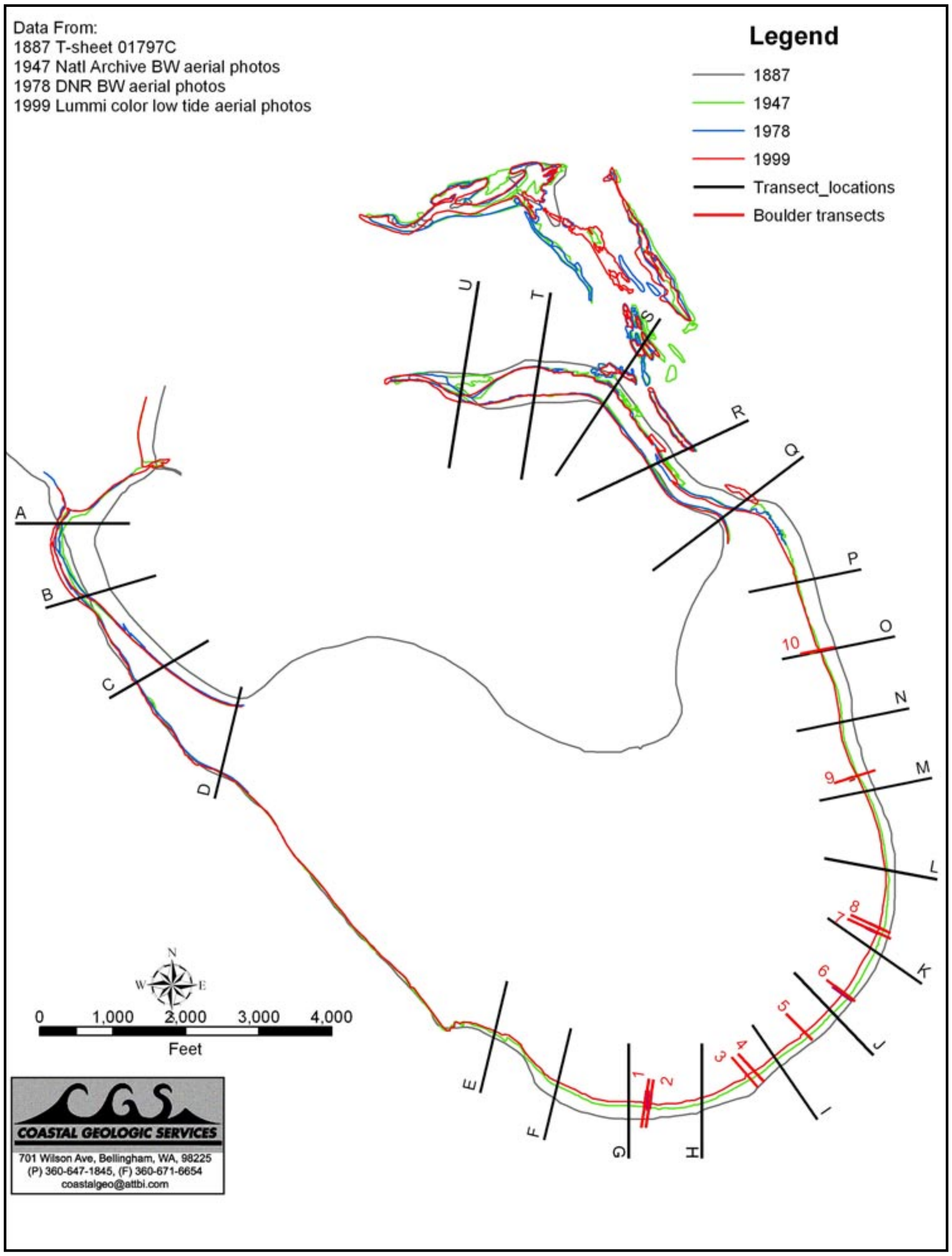

Figure 5. Locations of transects used for shoreline analysis.

Table 3a, b, and c. Accretion and erosion rates (cross-shore) in ft/year, using Beach (HT/LT) shoreline at The Portage (a), S and E Portage Island (b), and Brant Spit (c). Positive numbers denote accretion, negative numbers denote erosion. ES=Exposed shoreline, BS=Bayside shoreline.

a. The Portage

Transect		A		B		C		D		Mean	
		ES	BS	ES	BS	ES	BS	ES	BS	ES	BS
Time Period	1887 - 1947	-0.42	-7.72	1.40	-5.33	-0.08	-2.88	-0.50	-1.80	0.10	-4.43
	1947 - 1978	1.19	-2.74	1.06	-0.23	-0.32	0.55	-0.65	0.39	0.32	-0.51
	1978 - 1999	0.52	-0.43	2.67	-1.52	0.67	-0.86	0.33	-0.52	1.05	-0.83
	1887 - 1999	0.21	-4.97	1.54	-3.21	-0.01	-1.55	-0.38	-0.96	0.34	-2.67

b. S + E Portage Island

Transect		E	F	G	H	I	J	K	L	M	N	O	P	Mean
	1947 - 1999	-0.44	-1.08	-1.12	-1.44	-1.27	-1.40	-1.56	-0.56	-0.73	-0.81	-0.13	-0.40	-0.91

c. Brant Spit

Transect		Q		R		S		T		U		Mean	
		ES	BS	ES	BS	ES	BS	ES	BS	ES	BS	ES	BS
Time Period	1887 - 1947	-3.38	-1.35	-2.42	-0.02	-1.35	-0.72	-1.27	-1.62	-3.72	1.27	-2.43	-0.49
	1947 - 1978	0.77	0.35	-3.03	0.87	-0.58	1.00	-0.06	-0.32	-1.10	1.77	-0.80	0.74
	1978 - 1999	-1.19	1.05	3.71	0.57	-0.43	0.67	-0.52	0.43	-1.86	2.19	-0.06	0.98
	1887 - 1999	-1.82	-0.43	-1.44	0.34	-0.96	0.02	-0.79	-0.88	-2.64	1.58	-1.53	0.13

The gap between the MHW line of Portage Island and the Lummi Peninsula revealed that a significant portion of The Portage has lowered over the years, changing from a gap of only 517 ft in 1887 to 1,646 ft in 1967 and 1,653 ft in 1989 (Table 4). The rate of gap widening was greatest from 1887 to 1967 at 14.1 ft per year. From 1967 to 1989 the gap only increased 0.3 ft per year marking a significant decline in the rate of lowering at The Portage, suggesting that the tombolo may be reaching a new equilibrium.

Table 4. Linear distance between the NW point of Portage Island to the Lummi Peninsula.

Year	Distance (ft)	Rate (ft/yr)
1887	517	0
1967	1646	14.1
1989	1653	0.3

Brant Spit—Brant Island and spit narrowed from 1887 to 1947 along all transects except transect U which showed slight accretion along the bayside shoreline side (Table 3c). From 1947 to 1978 Brant Island and spit moved to the west and south marked by erosion along the exposed shoreline and accretion along the bayside shoreline. There was an overall widening of the spit base (transect Q), and a narrowing of the northwest end of Brant Spit (transect T). The westward migration of the spit continued from 1978 to 1999 with a widening of the neck of the spit along transect R.

North Spit Growth—The North Spit grew more rapidly at the beach (HT/LT) feature when compared to the MHW feature (Table 5). Significant progradation of 1,238 ft occurred at MHW at North Spit between 1887 and 1947. The greater progradation appears to occur at the high tide-low tide break in slope of 2,092 ft. After a cycle of minimal erosion from 1947 to 1978, accretion was again the trend here.

While the nautical charts didn't provide as much hydrography detail as the 1887 and 1956 H-sheets, trends were evident. The broader open water area in 1887 allowed for maintenance of multiple deep channels (Figure 6). Progradation of both North Spit and the subtidal beach along the Lummi Peninsula caused a "consolidation" into a single channel by 1926. This channel was narrowed and deepened between 1926 and 1956. The channel was slightly narrowed further after 1956, and apparently partially infilled. The channel has been maintained by the scouring effect of tidal currents during lower water levels, also put forward by Vonheeder (1972).

Table 5. Linear growth and direction of the North Spit.

Feature	Time Period	Growth (ft)	Direction
MHW	1887-1967	1,238	SW
	1967-1989	-23	NE
Beach (HT/LT)	1887-1947	2,092	WSW
	1947-1978	-50	SE
	1978-1999	144	WNW

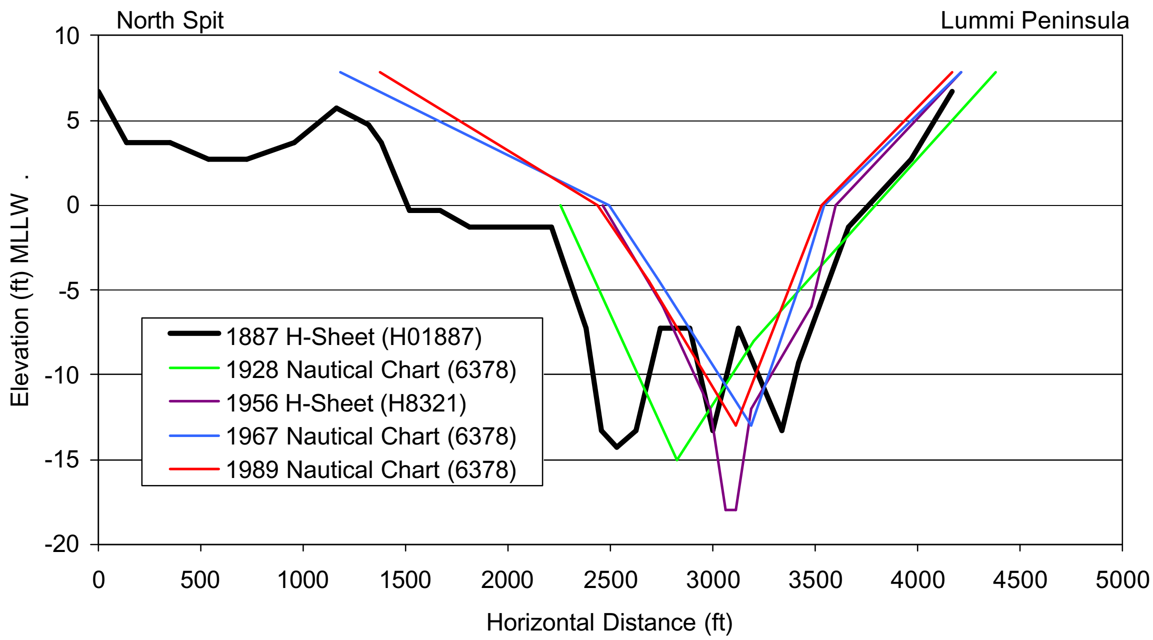

Figure 6. Transect through the North Spit heading NNW to the Lummi Peninsula.

Bluff Toe Erosion Using Point Measurements

The southern and eastern shorelines of Portage Island experienced intermittent accretion and erosion from 1947 to 1999, ranging from an average of 1.9 ft/yr of erosion at transect 5 at the southern end of Portage Island to 1.2 ft/yr of accretion near the northeastern shoreline (Figure 5, Table 7). Results from point measurements were independent of any spatial error, as all measurements were specific to a small area of each orthorectified image, such that the limited data points from this period could reflect a period of low or no bluff erosion that included revegetation of the bluff toe area.

Forty-two bluff erosion point measurements were made in this study. There was bluff erosion between 1969 to 1978 along the eastern shoreline of Portage Island of up to 3.7 ft/yr. The highest mean erosion rates over the entire period of data were at the southeastern portion of the island at 0.8 to 1.9 ft/yr. From 1978 to 1987 there was minor accretion and stability along the southeastern shore of Portage Island. Erosion occurred from 1978 to 1999, with accretion along the northeastern shore from 1995 to 1999.

Table 7. South bluff toe erosion rates in feet/year. Transect 1 is on the southwest end and 10 is to the northeast (see Figure 10).

	1947-1978	1947-1969	1955-1969	1966-1969	1969-1978	1978-1987	1969-1987	1978-1999	1987-1995	1987-1999	1995-1999	Mean
1	0.7							-0.9				-0.1
2	0.6							-1.0				-0.2
3							0.4		0.6			0.5
4									-0.9			-0.9
5							0.1		-3.9			-1.9
6			2.6		-3.7	0.3			0.0		-3.2	-0.8
7		2.0			-2.4	0.0			0.0		-3.4	-0.8
8		1.1			-1.9	0.0				-0.3		-0.3
9		-0.6			0.8	0.9			-0.3		1.7	0.5
10				1.3			-0.2		-0.5		4.2	1.2
Mean	0.6	0.8	2.6	1.3	-1.8	0.3	0.1	-0.9	-0.7	-0.3	-0.2	-0.3

Sediment Characterization

Sediment samples were collected from Portage Bay in the area below MLLW. Sediment samples were not collected from the beach area landward of MLLW in order to stay focused on the bay and not be over extended by the highly variable high-tide beach area. Sampling the area landward of MLLW would have required that a much larger number of sediment samples be collected and processed. Aditionally, the high-tide beach sediment composition varies significantly during the year as well as over a cycles of approximately 3 to 8 years, so that mapping would soon be obsolete.

Between the period of June 11 and November 4, 2002, a total of 84 sediment samples were collected in an attempt to characterize the sediments in Portage Bay. A small boat was used to collect 38 marine samples by means of a Petite Ponar grab sampler, located with a Garmin Etrex Venture GPS unit. During low tides, 46 grab samples were collected on foot and were located with a Garmin Etrex Venture GPS unit. All samples were dried and qualitatively examined for differences in grain size and location in order to select 53 representative samples that covered Portage Bay. The 53 samples were sent out to an outside lab for grain size analysis.

A sample of sediment distribution results is shown in Figure 12 and 13. Results are discussed in the *Summary and Conclusions* section.

Net Shore-drift Interpretation

The interpretation of net shore-drift presented here is based on field reconnaissance completed for this study during the summer and fall of 2002, past visits to the study area between 1992 and 2001, historic aerial photographs, previous net shore-drift mapping, and data presented in other sections of this report. Drift cell numbers in this section will follow those created by Jacobsen (1980).

Southern Portage Island

Although the erosion rate estimates for southern and southeast Portage Island vary, the trend of erosion of the high bluffs is clear and is shown in Figure 7. Sediment has not been accumulating at the beach on southern Portage Island; instead it has been transported by waves generally northward. The zone of drift divergence mapped by Jacobsen at southern Portage Island was quite broad (4,400 feet). Assessment as part of this study has refined the zone of drift divergence into a narrower area, with a length of 2,600 feet (Figure 8). This divergence area starts at the southernmost point of Portage Island and extends to the east-northeast.

Figure 7. Recent landslide deposits over upper beach at SSE Portage Island. Note person atop colluvium. Photo taken 11/4/02 by CGS.

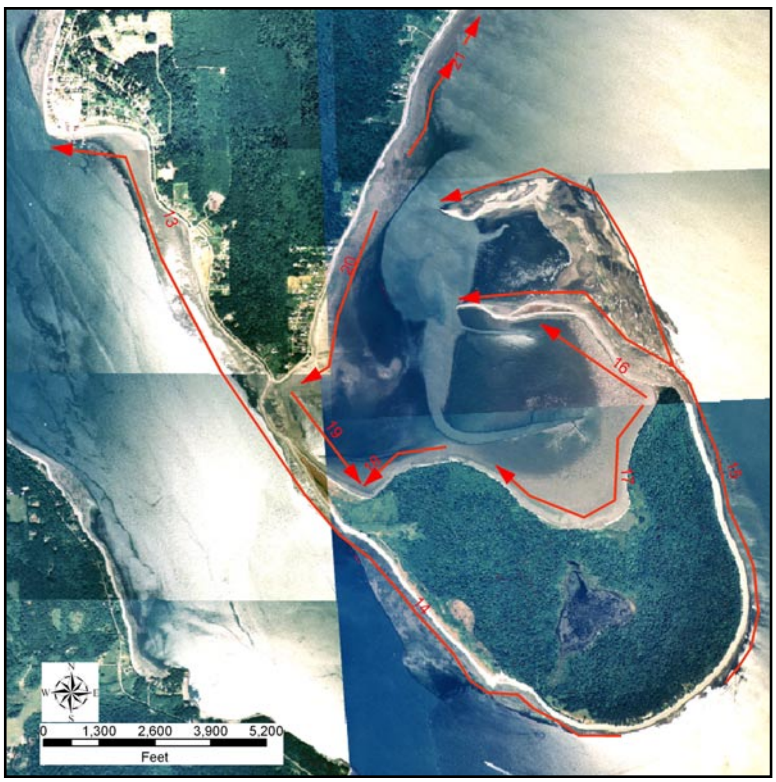

Figure 8. Net Shore Drift Analysis for 2002 Portage Bay Study. Background is 6/14/99 low tide image by Walker & Associates. Numbers denote drift cells named by Jacobsen (1980).

Western Portage Island and The Portage

Drift cell 14 continues to the northwest along the west shore of Portage Island all the way to Fisherman's Cove and Gooseberry Point. This shore contains a large reach of low sand and gravel berm fronting a marsh and low backshore area, termed an "accretion shoreform" by Bauer (1974). This area does not appear to have changed significantly since 1887. Excavations in this low elevation area were carried out in 1982 by archeologists who found "beach deposits" below the surface more than 500 ft from the 1982 beach location (Griffin 1983).

Figure 9. Oblique aerial image of the northern, intertidal portion of The Portage looking east into northern Portage Bay. Lummi Peninsula is to left (north). Note small bar-top drainage channel. Photo no. 010524-131412 by WA DOE taken 5/24/01 at predicted tide level of –1.3 ft MLLW.

North of the low west shore of Portage Island, a portion of drift cell 14 goes along an erosional low bluff (Figure 8). The shore of The Portage becomes an accretion spit located in the southern vegetation section of The Portage, continuing northwestward until the spit becomes intertidal, and is therefore now a bar (Figure 9).

Some of the sediment from cell 13 may contribute to the volume of the intertidal bar as suggested by Schwartz (1995), but a good portion of this sediment appears to continue to Jacobsen's (1980) cell 13, making these cells in fact a single complex net shore-drift cell extending up to Gooseberry Point. Some sediment is likely lost along the center of the cell under some conditions, such as a high tide with northwest winds. However, it is likely that there is a net transport of sediment westward over The Portage bar due to tidal currents that usually flow westward at a moderate to high velocity.

Eastern Portage Island and Spits

Net shore-drift runs generally northward along the east shore of Portage Island. Jacobsen's drift cell is consistent with data and observations in this report, as well as conclusions of Bauer and Schwartz. However, the previous mapping efforts and discussion by Schwartz seem to have completely ignored the North Spit (USGS "Brant Island" area; Figure 8). Drift cells were drawn as ending at the distal end of Brant Spit, with no connection or explanation offered for the formation of North Spit.

The geomorphic history of the spits must have been the progradation of Brant Spit first, followed by the very gradual buildup of the large spit platform extending more north-northwestward in line with the shore of Portage Island nearby. The volume of the subaqueous spit platform is immensely greater than the intertidal and higher portions of North Spit, however the best mapping delineates only the MLLW and high water marks, and discussion here will focus of these intertidal areas. A portion of the northern end of North Spit had formed into an island by 1855 and persisted in 1857, and significant accretion above MHW occurred during the 1900s. Sediment for the large volume increase at North Spit was transported from Portage Island during times of low-mid tide. When tide levels were high, waves transported beach sediment along the steeper upper beach of Brant Spit. Therefore, the net shore-drift cell currently has two termini, one at the end of each of large spit/bar, as drawn in Figure 8.

An area near the base of Brant Spit became eroded and lowered during the winter of 2001-2002. At a tide level of just below MHHW in Bellingham (at approximately +8.2 to +8.4 ft MLLW) the base of Brant Spit becomes flooded, as observed during November 2002. This was occurring over an approximately 250- to 300-ft long area, which was completely devoid of drift logs.

A portion of the narrow neck of Brant Spit has been low and narrow in different times during the air photo record (1947-2001; Figure 10). Presumably, portions of Brant Spit had similar characteristics to conditions observed in late 2002, although accurately determining the elevation of the narrowest part of the spit in historic air photos was not possible. All

Figure 10. Oblique aerial image of Brant Spit and a portion of North Spit looking NW, in the direction of net shore-drift. Lummi Peninsula is in upper portion. Note narrow and slightly lower elevation portion of the spit (left) and prograded distal end of spit, as well as the base of North Spit in the lower portion. Photo no. 010524-131754 by WA DOE taken 5/24/01 at predicted tide level of –1.3 ft MLLW.

of the historic air photos examined in detail had at least some amount of low area visible along the narrow neck of the spit. Relative locations of these low areas were measured with a high precision caliper directly from the 9x9 inch contact prints that were also scaled. Results of this exercise are presented in Table 8.

Table 8. Location and length of low portions of Brant Spit 1941-2001.

Year	Base Brant spit-beg. low area (ft)	Base Brant spit-end low area (ft)	Length of low area (ft)	Percentage of total length (ft)
1941	1836	2424	588	22
1947	2022	2569	547	21
1970	1061	1268	208	8
1978	1807	2462	655	25
1987	1862	2493	631	24
1995	2013	2456	442	17
1999	637	1098	461	17
2001	594	1069	475	18
Mean			501	19

The data show that the 2001 low area was comparable in length to past years, but occurred near the base of the spit, as opposed to most other years, where the low was further to the northwest. An oblique aerial photo taken around 1979 in Jacobsen (1980) shows a long low-elevation area on the northwest part of the neck of the spit that was devoid of drift logs.

Qualitative conditions at the neck of Brant Spit were determined from air photos and are presented in Table 9. The elevation of the low area in 2002 was likely lower than most of the past years based on a limited amount of local information. The oscillation between a low northwestern portion and a low southeastern portion seems to have occurred every 10-20 years or so, based on incomplete data. Review of additional photos would aid in refining that apparent cycle, only examined late in the study period.

Table 9. Relative changes along the neck of Brant Spit 1941-2001 from air photos.

Year	SE Third	Middle	NW Third
1941	wide?	wide?	very low
1947	wide	wider	very low
1970	narrowed	low (S)	wider
1978	wider	wider (S), narrowed (N)	low
1987	wide	wide	very low
1995	low	wide	recovering
2001	lower	wider	wider

Summary and Discussion

Shoreline Change – General

Shoreline change trends were analyzed in this study using a variety of methods. Early maps, map field notes, sketches, and oral histories covering the period before 1890, were qualitatively reviewed. The early maps and other information sources were critical to this study, as they documented the most significant change to the shoreline (and likely the water circulation) of Portage Bay in the entire historic record. Shoreline change was quantitatively mapped as the data allowed from 1887 to 1999. Point measurements of accretion/erosion were made for areas where the horizontal control of early mapping was not adequate, such as at southern Portage Island. The most significant changes identified were at The Portage and along Brant Spit and North Spit, as described below.

Shoreline Change at The Portage

Changes at The Portage, prior to the first fairly reliable maps made in 1887, were documented by local Historian Tim Wahl (synthesized for this study). A series of early maps made between 1792 and 1858 (presumably qualitatively accurate if not spatially accurate) show The Portage as a supratidal feature (see Figure 11 for example). More detailed maps from this period show The Portage as covered with prairie vegetation. The presence of a prairie at The Portage means that the tombolo was likely at approximately elevation +11 to +12 ft MLLW. This entire spit was apparently mapped as arable land in 1871, strongly suggesting that The Portage was entirely above the reach of normal high tides.

Recorded oral accounts summarized by Wahl also attest to a wider landform that was above the reach of normal high tides in 1855, which is now underwater at MHW. Several accounts say that The Portage was lowered artificially in the late 1870s or early 1880s through hand digging and/or blasting. Increased wagon and other traffic followed, presumably destroying vegetation and allowing for increased erosion. One account not specifically cited in work for this study by Wahl also described the Portage soon before 1860 (from Griffin 1983, citing earlier work by Wayne Suttles):

> "What is now 'the portage' is a mere crescent of gravel that connects the south tip of the peninsula with Pt. Francis (Portage Island) at low tide. In the middle of the last century this strip was a broad gravel prairie over which canoes were portaged between Hale Passage and Bellingham Bay."

Once The Portage was breached it appears that the lowering of the bar was a positive feedback system in that tidal currents, which appear to go westward most of the time, have further eroded the tombolo while it also shifted westward (Figures 2-4). The gap between the locations of MHW on each side of the low portion of The Portage increased at a rapid rate of 14.1 ft/yr (Table 4) between 1887 and 1967, and slowed considerably afterwards. This would suggest that the position of The Portage has reached some equilibrium following roughly 100 years of erosion.

The elevation of the low area of The Portage has varied over time, although few actual data points exist. Only three data points and one descriptive report by a qualified surveyor were found in this study. Gilbert stated in 1887 that Portage Island "is connected… at half tide" with the Lummi Peninsula. Hydrographic sheet no H-8321 contains a note saying that The Portage dries at +4.0 ft MLLW. An archeological investigation (Griffin 1983) stated that The Portage was "visible at a +5.3 ft MLLW tide or lower". While the accuracy of the previous observation is not clear, it is supported by a statement in Vonheeder (1972) that suggested shoaling of the low portion of The Portage occurred in recent decades:

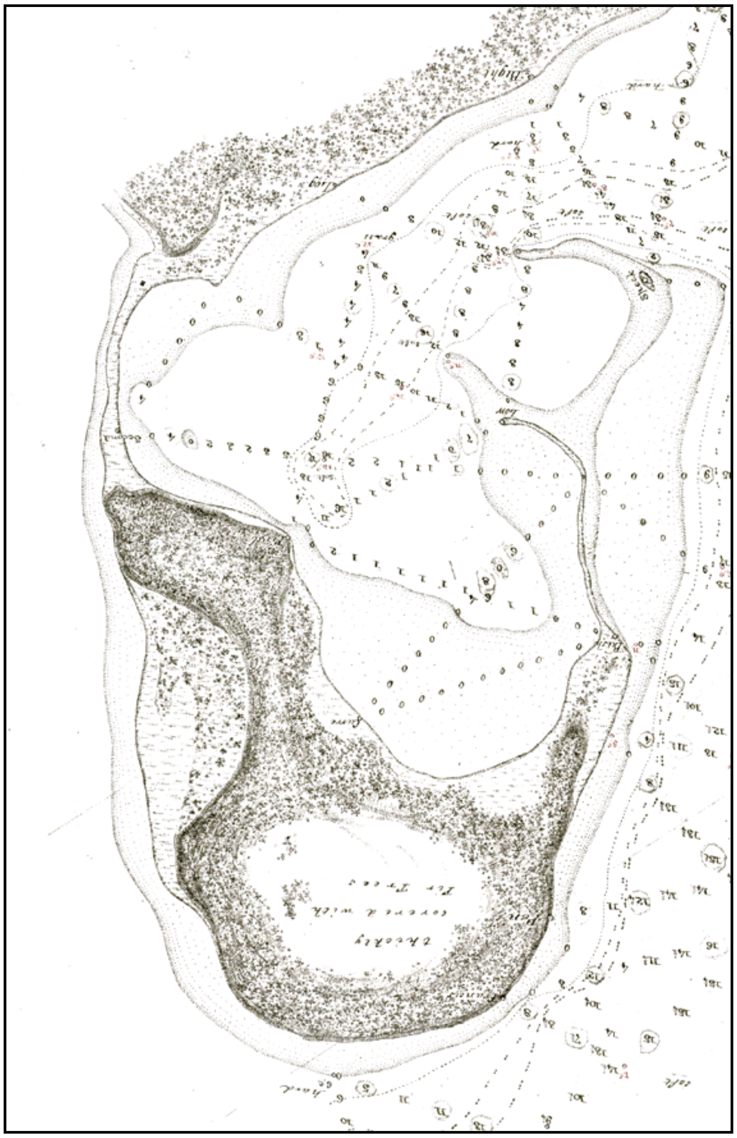

Figure 11. Map from 1855 by the US Coast Survey (Alden, McMurtrie). This is the first detailed hydrographic survey of Bellingham and Portage Bays. Note continuous prairie vegetation at The Portage.

> "Fishermen in the area says that the recent accretion of [The Portage] now prohibits the passage of their boats, but at one time The Portage was navigable during high tide."

The third elevation information for The Portage is observations from late 2002 for this study that noted the time of emergence of the lower portion of the tombolo and used preliminary recorded water levels from the nearby Cherry Point NOS tide station. The equivalent Bellingham tide was +4.0 ft MLLW for emergence of The Portage.

The Portage moved westward and has still not regained its elevation or width. Although the sediment input from Portage Island is largely unchanged, reduced sediment input from the southern end of Lummi Shore Road and Hermosa Beach, where the bulkheads are near continuous, is a likely contributing factor in this.

Shoreline Change at Brant Spit and North Spit

Brant Spit lengthened approximately 768 ft between 1887 and 1989. Careful examination of the original aerial photographic prints revealed that the narrow "neck" of the Brant Spit (approximately 2,660 ft in length) has experienced regular changes in width and elevation of the berm crest. The important finding is that at the time of most of the historic aerial photos, some portion of Brant Spit was devoid of drift logs and appeared at a reduced elevation. This low area was usually along the northwest portion of the neck but in 1970 and 2001 the low area has been located closer to the southern

Figure 12. Oblique aerial image of net shore-drift divergence zone at SSE Portage Island. Photo no. 010524-131622 by WA DOE taken 5/24/01 at predicted tide level of –1.3 ft MLLW.

end of the spit. There appears to have been periods (of unknown duration) when portions of the neck of the spit were likely overwashed during higher, high tides.

The intermittent lowering of Brant Spit has likely occurred as a result of the growth of the large spit platform that contains North Spit (and the USGS-termed "Brant Island") and progradation of the north and northwest portions of North Spit. Essentially, an increasing proportion of the net shore-drift sediment that had been transported from Portage Island to Brant Spit now bypasses Brant Spit and is transported more northward to the extensive flats and prograding gravel and sand North Spit (Figures 2-4). The low elevation area near the base of Brant Spit that occurred at least as early as 1999 and persists through late 2002 is the latest manifestation of this phenomenon.

Portage Island Bluffs

The southern and southeastern shore of Portage Island (where Point Francis is located) contains bluffs between 100 and 160 ft high. This area experiences intermittent episodes of toe erosion due to storm wave attack at higher tides, and subsequent landsliding. The area is shown in Figure 12 in 2001, after a period of several severe then mild weather winters. Bluff erosion here appears to occur at a highly irregular rate, since the area experiences less frequent and larger than typical bluff toe retreat episodes (landslides). The beach at the southern portion of Portage Island has a gravel beach (composed of pebble, sand, and cobble). Large boulders are also present in the intertidal and sub tidal area. The boulders are known as a lag deposit, as they were derived from the bluff erosion that simply caused the boulders to drop in place as the bluff face receded. The presence of these boulders and the shoal that extends to the south-southeast indicates that the island has experienced erosion over tens of thousands of years. Other evidence of the long-term nature of bluff retreat here is the drawing of a mostly unvegetated bluff face at south and southeastern Portage Island (Point Francis) in 1887.

Some of the erosion rates at south and southeast Portage Island derived from GIS shorelines in this study appeared to be over-estimates and were not presented in the erosion rate section. The earliest map used in this study was from 1887 (Figure 4), but this map likely had some spatial errors associated with the more far-flung southern portions of Portage Island. In addition, the actual shoreline used from that 1887 map was delineated by slightly different field methods than were the later shorelines. There was also a significant lack of ground control features in this southern portion of the study area, such that the spatial control of the orthorectified images was not as good as the other portions of the study area and images were not perfectly aligned. When compared to erosion rates by Vonheeder (1972) and well-documented erosion rates for other sites in the region (Schwartz and Wallace 1986), the GIS derived erosion rates also seemed too high. Therefore, point measurements were carried out.

Point measurements of bluff toe recession were completed for the south and southeastern shore of Portage Island between 1947 and 1999 (Figure 5 and Table 7). Overall, erosion rates were greatest near Point Francis at southeast Portage Island. This was consistent with qualitative observations, past work by Vonheeder (1972), and the net shore-drift mapping for this and other studies (Jacobsen 1980, Bauer 1974).

Relatively rapid erosion rates were documented during the periods 1969-1978 and 1995-1999, which coincided with periods of numerous widespread precipitation-induced bluff failures and bluff retreat around the region (Tubbs 1974, Gerstel and others 1997). The long-term mean erosion rates at the southeastern portion of the island were the highest at 0.8 to 1.9 ft/yr, which was higher than the rate put forward by Vonheeder of 1.5 inches/yr (0.125 ft/yr) which was based on only one data point over one time period. The lack of more data in the study by Vonheeder suggests that data from this study should be taken as more conclusive. Also, when compared to other sites in the region (Schwartz and Wallace 1986) the rate of 0.125 ft/yr does not seem probable.

Sediment Distribution
Sediment data were processed for grain size for 53 sample locations around Portage Bay and a series of sediment distribution maps were prepared (Figures 13 & 14). Sediment distribution results supported results and assessment of other aspects of this study. Sediment grain size distribution suggests that material is being eroded on the southern end of Portage Island and being transported to the north. The transport of relatively coarse material has enlarged Brant Spit and created the North Spit.

Coarse sand and gravel were dominent (more than 80% of samples by weight) north of Brant Spit and north and northwest of the North Spit (Figure 13). High concentrations of coarse sand and gravel were also at The Portage and just northeast of the Portage in shallow nearshore areas extending along the Hermosa Beach portion of Lummi Shore Road.

The sediment distribution of Portage Bay was examined in terms of percent (by weight) of silt and clay. The southern half of the bay is in excess of 50% silt and clay, with a relatively sharp gradation between across the southern portion of Portage Bay, with very high percentages of fines in southern Portage Bay. This material erodes from other locations and settles in this very protected environment.

Between North Spit and the Lummi Peninsula, coarse sediment dominated as finer material is likely transported out of the channel area due to relatively strong tidal currents.

Net Shore-drift
Coastal Geomorphologic trends and features, erosion and accretion trends, erosion rate measurements, and sediment distribution data have all assisted in interpretation of net shore-drift patterns defined in this report. Results of this analysis of net shore-drift in the Portage Island and Portage Bay area are presented in Figure 8. A Zone of drift divergence exists at the south and southeast Portage Island, but this study mapped this area as narrower (2,600 ft) than previous work by Jacobsen. Net shore-drift at the outer shores of Portage Island is generally northwestward, forming the tombolo known as The Portage and the large Brant Spit and North Spit on the east. The drift cell that includes The Portage appears to continue past The Portage to the northwest, extending all the way to Gooseberry Point. However, this long cell does not have direct connection at high water. Continuation of the cell beyond The Portage is in contrast to previous net shore-drift mapping by both Jacobsen (1980) and Bauer (1974).

Net shore-drift runs generally northwest from Portage Island to both Brant Spit and North Spit. Both previous mapping efforts (Jacobsen 1980, Bauer 1974) and discussion by Schwartz (1995) did not directly mention the North Spit (USGS "Brant Island") area. Drift cells were drawn as ending at the distal end of Brant Spit, with no connection or explanation offered for the formation of North Spit. This study mapped a net shore-drift cell extending both along the east shores of Brant Spit and North Spit. The majority of net shore-drift sediment apparently goes along North Spit during all but higher tides, as evidenced by the larger intertidal area and the higher rate of accretion at North Spit.

Another variation from previous mapping is that a small amount of sediment likely continues northwest from North Spit across to the Lummi Shore Road beach near the south end of the Seining Grounds. More research into this should be conducted in the future.

In general, the net shore-drift interpretation of Jacobsen was determined to be mostly correct, with a greater amount of connectivity between drift cells than Jacobsen had. The Bauer study is not considered valid for this area.

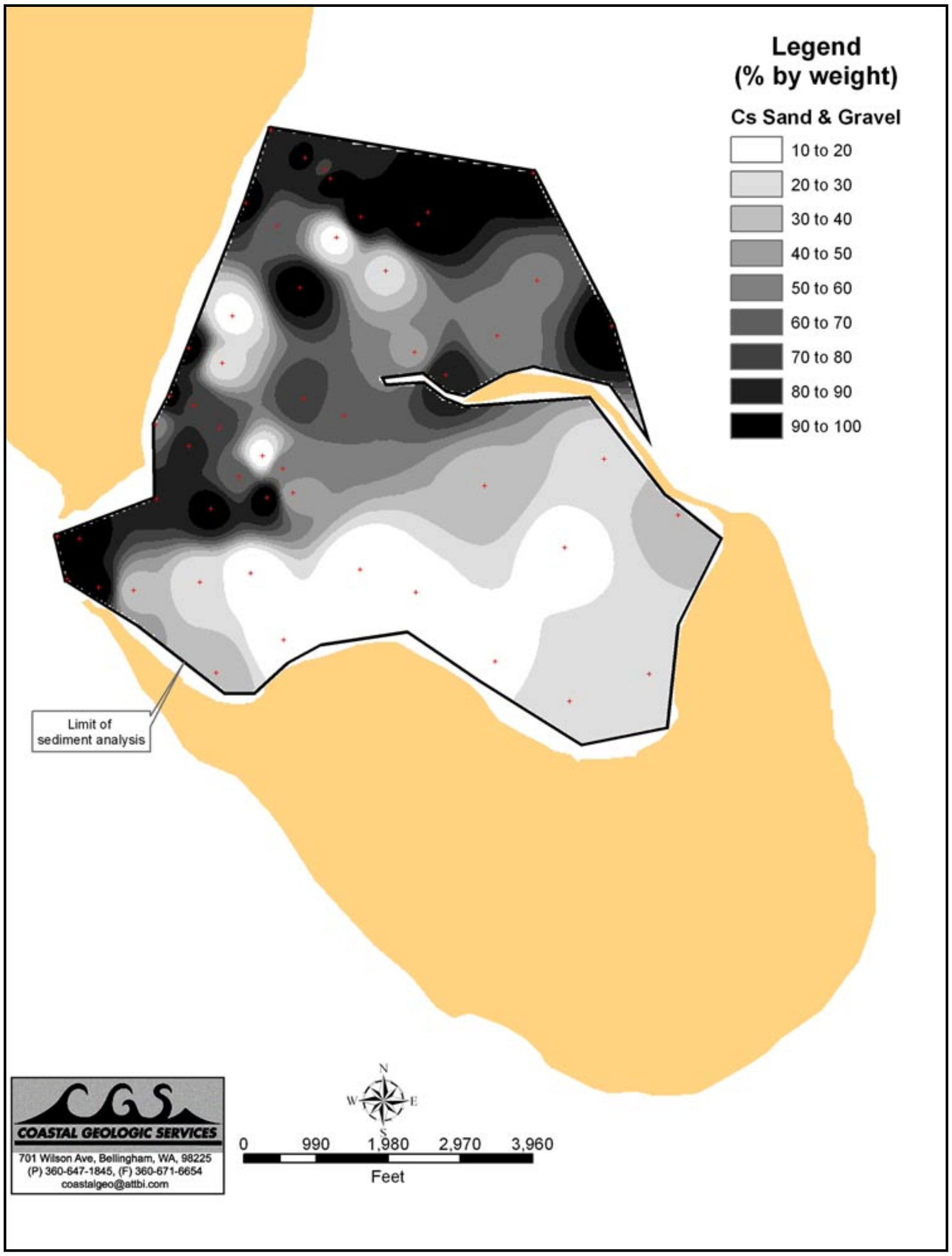

Figure 13. Portage Bay Sediment Analysis- Cs Sand & Gravel (% by weight).

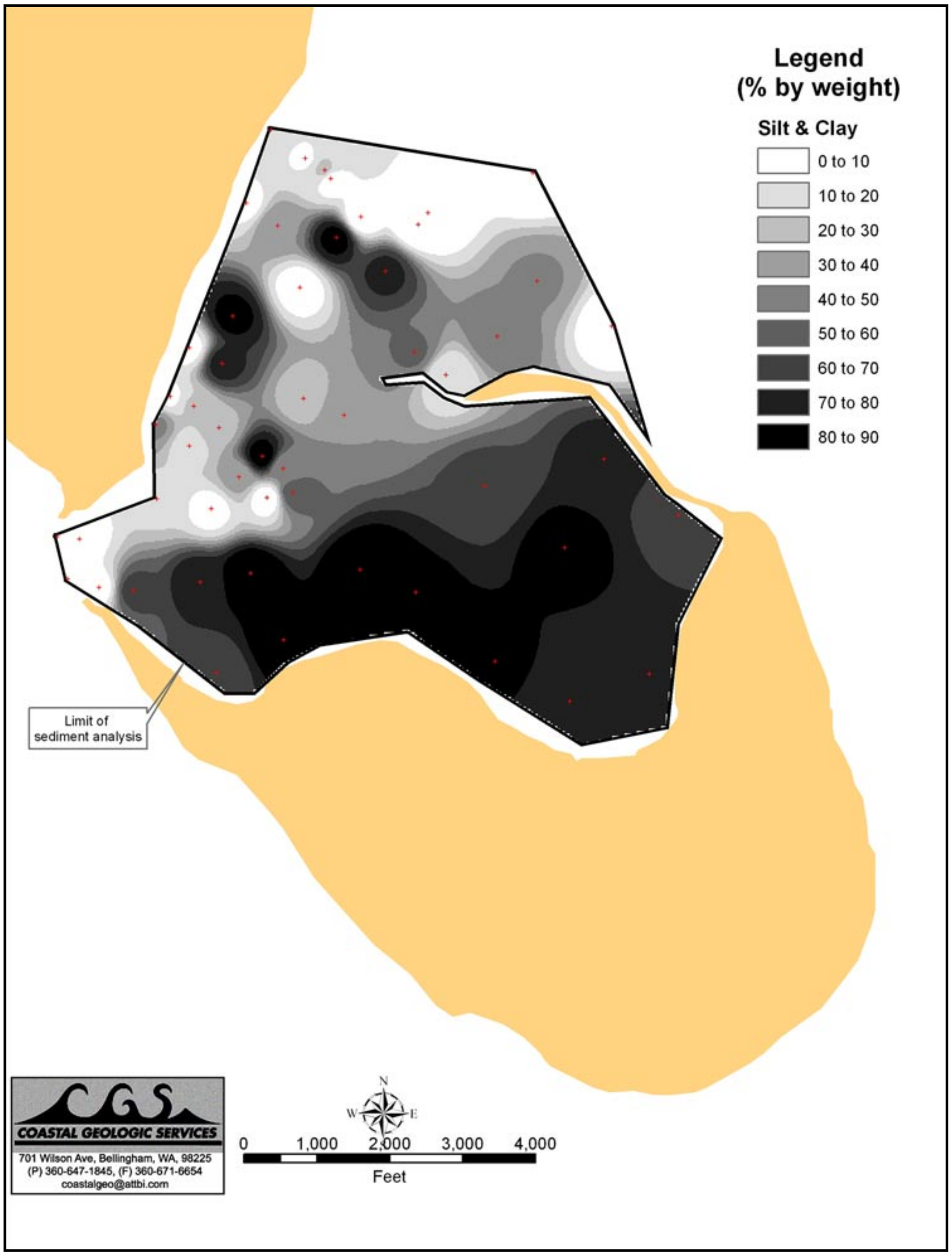

Figure 14. Portage Bay Sediment Analysis- Silt & Clay (% by weight).

Changes in the elevation and location of The Portage, Brant Spit, and North Spit have considerably altered the shape and hence water circulation patterns of Portage Bay since the mid 1800s.

Recommendations for Further Study

One of the primary long-term goals of this study has been to define geologic processes in order to allow for an improved understanding of water circulation patterns in the Portage Bay area. Changes in the elevation and location of The Portage, Brant Spit, and North Spit, along with changes documented in the area north of North Spit have considerably altered the shape and hence water circulation patterns of Portage Bay since the mid 1800s.

The findings of the study suggest that several naturally occurring processes should be monitored to build on our understanding of processes and document continued changes accurately to provide needed insight into actions that could be undertaken to reduce contaminant input into the Portage Bay shellfish beds.

The following specific recommendations are provided:

1. Quantitatively monitor, through precision surveying, changes in elevation and position of The Portage bi-annually to define trends.

2. Quantitatively monitor, through precision surveying, changes in elevation and position along the neck of Brant Spit (where the occurrence and presence of low elevation areas has varied) bi-annually to define trends.

3. Measure water circulation patterns in Portage Bay during a wide variety of wind and tide conditions through the use of a large assemblage of drifters and an accurate tracking system.

4. Model water circulation through running several appropriate models to create a relatively accurate model for use in assessing the fate of contaminants from different sources and to test the sensitivity of different configurations of the spits (elevation and length).

5. Coordinate water circulation study efforts with Lummi staff and others who have data and/or information on past circulation work and present conditions in Portage Bay.

6. Collect new bathymetry data in Portage Bay for modeling with particular attention paid to the area between North Spit and Brant Spit and the Lummi Peninsula. Quantitative comparison to the high quality bathymetry data from 1956 would provide an additional useful comparison of subtidal changes in the bay.

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